
SHORT COMMUNICATIONS

Alum Treatment of Poultry Litter: Decomposition and Nitrogen Dynamics

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Abstract

While the poultry industry is a major economic benefit to several areas in the USA, land application of poultry litter to recycle nutrients can lead to impaired surface and ground water quality. Amending poultry litter with alum [$\text{Al}_3(\text{SO}_4)_2 \cdot 14\text{H}_2\text{O}$] has received considerable attention as a method of economically reducing ammonia volatilization in the poultry house and soluble phosphorus in runoff waters. The objective of this study was to characterize the effect of alum on broiler litter decomposition and N dynamics under laboratory conditions. Litter that had been amended with alum in the poultry house after each of the first four of five flock cycles (Experiment I) and litter that had been amended with alum after removal from a poultry house after the third flock cycle (Experiment II) were compared with unamended litter in separate studies. The litters in Experiment I were surface-applied to simulate application to grasslands, while the litters in Experiment II were incorporated to simulate application to conventionally tilled crops. The only statistically significant differences in decomposition due to alum occurred early in Experiment II and the differences were small. The only statistically significant differences in net N mineralization, soil inorganic N, and soil $\text{NH}_4\text{-N}$ in either experiment was found in Experiment I after 70 d of incubation where soil inorganic N was significantly greater for the alum treatment. Thus, alum had little effect on decomposition or N dynamics. Results of many of the studies on litter not amended with alum should be applicable to litters amended with alum to reduce P availability.

POULTRY LITTER refers to a mixture of bedding and poultry manure, a by-product of poultry production. Bedding materials such as wood shavings, rice hulls, or sawdust are added to the floors of poultry houses and several flocks of birds are grown on it for up to one year. At the end of this time, the litter is removed and land-applied (Moore et al., 1995).

Potential health and environmental effects associated with land application of litter have received increasing attention since the early 1990s (Sharpley et al., 1994). Nitrogen in litter applied to pastures may be nitrified, potentially entering ground and surface waters as $\text{NO}_3\text{-N}$. Furthermore, land-applied litter can increase

soluble reactive and particulate phosphorus concentrations in surface waters through runoff and erosion. Phosphorus contamination does not pose a direct health hazard, but instead degrades water quality by contributing inorganic P to surface water leading to eutrophication. Phosphorus is generally seen as the limiting nutrient in this process, and litter often contains greater than 2000 mg kg^{-1} water-soluble P (Moore and Miller, 1994).

Because soluble P in litter poses a significant threat to water quality in areas with intensive poultry production, the conversion of this P to less soluble forms has received increasing attention. One method that has come to the forefront is the addition of alum to bedding material or litter before birds are grown on the litter. Alum not only lowers levels of available P by precipitation with aluminum, but reduces NH_3 volatilization in poultry houses and runoff losses of soluble organic C as well (Moore and Miller, 1994). The reduction in NH_3 levels has the twofold effect of improving bird health and raising the fertilizer value of the litter (Moore and Miller, 1994; Sims and Luka-McCafferty, 2002). With these benefits to growers and water quality, alum use represents an environmentally and economically attractive method for controlling nutrient losses from land-applied poultry litter.

The objective of this study was to characterize the effect of alum on broiler litter decomposition and N dynamics under laboratory conditions. Litter that had been amended with alum in the poultry house after each of the first four of five flock cycles (Experiment I) and litter that had been amended with alum after removal from a poultry house after the third flock cycle (Experiment II) were compared with unamended litter in separate studies. The litters in Experiment I were surface-applied to simulate application to grasslands, while the litters in Experiment II were incorporated to simulate application to conventionally tilled crops.

Materials and Methods

Experiment I

Captina silt loam soil (fine-silty, siliceous, mesic Typic Fragi-udult) at the University of Arkansas Main Station Farm was collected from the Ap (0–10 cm) horizon. Soil was sieved through a 4-mm mesh screen to remove foreign materials such as rocks and roots, and refrigerated at 4°C before use.

Broiler litter with a bedding of wood shavings was obtained from six separate poultry houses. The poultry houses were located on the same farm using the same production practices. Litter in three of the houses had been treated with alum, while

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litter in the remaining three houses was untreated. Thus, there were three replicates of the two treatments: litter alone and litter plus alum. For the three alum-treated houses, the litter was decaked after each batch of birds and alum was applied at a rate of 1360 kg per house following the first batch and 1820 kg per house for the remaining batches. Each house contained approximately 18 Mg of litter after each flock. After the fifth flock and before clean out, alum was not applied. Several samples of litter were collected from each house and frozen. These samples were thawed, foreign materials such as pebbles and feathers removed, and then mixed to produce one composite sample for each of the six houses. The composite sample was frozen.

Total nitrogen content for the dry soil and litters was determined with a LECO (St. Joseph, MI) CNS 2000 Elemental Analyzer. Carbon content of the soil and poultry litter was determined using a carbon train furnace at 900°C (Nelson and Sommers, 1996). Gravimetric water content for the soil was determined by placing 10 g of moist soil in a weighed porcelain crucible and drying in a microwave oven until a constant weight was reached. Water-holding capacity (WHC) of the soil was determined by saturating the soil in a weighed Gooch crucible from below and measuring gravimetric water content after initial, rapid drainage had ceased. Water content of the litters was determined in a drying oven at 46°C until a constant weight was reached.

Mason jars (710 mL) were used as incubation vessels. One hundred grams (dry equivalent) of soil were placed in each jar. The soil was then brought to 40% WHC with deionized water and mixed thoroughly for uniform soil moisture. Two grams of frozen litter were evenly spread on the soil surface and slightly wetted with deionized water. Base traps containing 20 mL 1 M NaOH were placed in each jar and the jars were sealed tightly and placed in an incubator at 25°C. Every 3 d, the incubation vessels were opened and aerated. The CO₂-C evolved was determined periodically by titration of the base traps with 1.0 M HCl after the addition of 1.5 M BaCl₂ (Zibilske, 1994). New base traps were placed in the incubation vessels each time CO₂-C was determined. The experiment was split into two parts due to space limitations in the incubator. Litters from Houses 2, 4, and 6 and a control (soil alone) were randomly chosen to be run first. Litters from Houses 1, 3, and 5 were run second including a second control.

Additional samples were set up for each run for inorganic N analysis. On Days 0, 42, and 70, a duplicate set was extracted with 1 M KCl using a 1:2 soil to water (w/v) extract. Jars were shaken every 15 min for 2 h. The jar contents were then vacuum-filtered using a disposable Nalgene (Rochester, NY) filter (0.45-μm) unit until 40 mL of filtrate was collected. Filtrates were refrigerated at 4°C before analysis. Ten-milliliter aliquots were analyzed for NH₄⁺-N and NO₃⁻-N using steam distillation (Mulvaney, 1996).

Experiment II

The soil was collected from the upper 15 cm of an area mapped as Cecil sandy loam (clayey, kaolinitic, thermic, Typic Kanhapludult) in the Georgia Piedmont. The sample was passed through a 2-mm sieve and wetted to 0.198 g water g⁻¹ before use (-0.02 MPa). Poultry litter (wood shavings bedding) was collected from a poultry house that had housed three flocks of birds before cleanout.

Treatments included a soil alone (120 g, dry equivalent), soil mixed with poultry litter (0.5 g fresh litter), and soil mixed with poultry litter amended with aluminum sulfate (0.1 g aluminum sulfate mixed with 0.5 g fresh litter). The soil or soil-litter mixture was packed into acrylic cylinders (4.45-cm i.d.,

10-cm length) to a bulk density of 1.29 g cm⁻³, and each cylinder was placed inside a 0.95-L glass jar. There were seven sets of experimental units, each set containing two replicates of the control treatment and three replicates of the litter treatments. The jars were placed inside an incubator at 25°C for 30 d. A 3-mL headspace sample was taken from one set of experimental units at various times during the experiment. The concentration of CO₂ in these air samples were determined with a Varian (Palo Alto, CA) Star 3600 CX gas chromatograph equipped with a thermal conductivity detector and a ⁶³Ni electron capture detector. At 0, 1, 3, 7, 17, 23, and 30 d, each experimental unit in one set was extracted with 1200 mL 1 M KCl for 30 min. The concentration of (NO₂⁻-N + NO₃⁻-N) in the extracts was determined by the Griess-Ilosvay technique after reduction of NO₃⁻ to NO₂⁻ with a Cd column (Keeney and Nelson, 1982). The concentration of NH₄⁺-N was determined by the salicylate-hypochlorite method (Crooke and Simpson, 1971).

Initial inorganic N in field-moist soil was determined by extracting 5 g soil with 40 mL 1 M KCl for 30 min and measuring NH₄⁺-N and NO₂⁻-N plus NO₃⁻-N as described above. Initial inorganic N in poultry litter was extracted by shaking 0.2 g litter with 40 mL 1 M KCl for 30 min. Total C and N in soil and total C in poultry litter was measured by dry combustion with a LECO 2000 CNS analyzer. Total N in moist poultry litter was determined with a micro-Kjeldahl method (Baker and Thompson, 1992).

Decomposition

Litter decomposition was defined using Eq. [1]:

$$\% \text{ decomposition} = (C_t - C_c) \times 100 \div C_{\text{total}} \quad [1]$$

where C_t is the CO₂-C evolved from the litter amended soil at time t , C_c is the CO₂-C evolved from the control soil at time t , and C_{total} is the total C added to the soil in the litter, all in units of mg C kg⁻¹ soil.

Nitrogen Dynamics

Net N mineralization was determined using Eq. [2]:

$$\% N_{\text{min}} = (N_t - N_c - N_0) \times 100 \div N_{\text{org}} \quad [2]$$

where % N_{min} is percent net N mineralization, N_t is inorganic N in the litter amended soil at time t , N_c is the inorganic N in the control soil at time t , N_0 is the inorganic N in the litter at time zero, and N_{org} is the initial organic N in the litter, all in units of mg N kg⁻¹ soil.

The extent of nitrification was determined using Eq. [3]:

$$\% \text{NH}_4^+\text{-N} = \text{NH}_4^+\text{-N} \times 100 \div (\text{NH}_4^+\text{-N} + \text{NO}_3^-\text{-N}) \quad [3]$$

where % NH₄⁺-N is the percentage of total soil inorganic N in the ammonium form, NH₄⁺-N is soil ammonium N, and NO₃⁻-N is soil nitrate N, all in units of mg N kg⁻¹ soil.

Statistics

The compare each pair feature of the fit Y by X platform (SAS Institute, 1996) was used to determine least significant differences.

Results and Discussion

Litter and Soil Characteristics

Analytical data for soils and litters are presented in Table 1. The Captina silt loam had a total carbon content

Table 1. Analytical data for soil and litter.

Property	Soil	Litter	Litter plus alum	LSD _{0.05}
g kg ⁻¹				
Experiment I				
Total C	7.1	348	317	14
Total N	—	40.8	45.2	4.2
Organic N	—	33.3	35.9	NS
C to N ratio	—	10.4	8.8	—
NH ₄ -N	0.009	4.7	8.2	NS
NO ₃ -N	0.004	2.8	1.1	NS
Water holding capacity	301	—	—	—
Water content	119	229	219	NS
Experiment II				
Total C	5.2	247	—	—
Total N	0.38	51.4	—	—
Organic N	—	47.2	—	—
C to N ratio	13.7	5.2	—	—
NH ₄ -N	0.0011	2.3	—	—
NO ₃ -N	0.0016	1.9	—	—
Water holding capacity	—	—	—	—
Water content	198	180	—	—

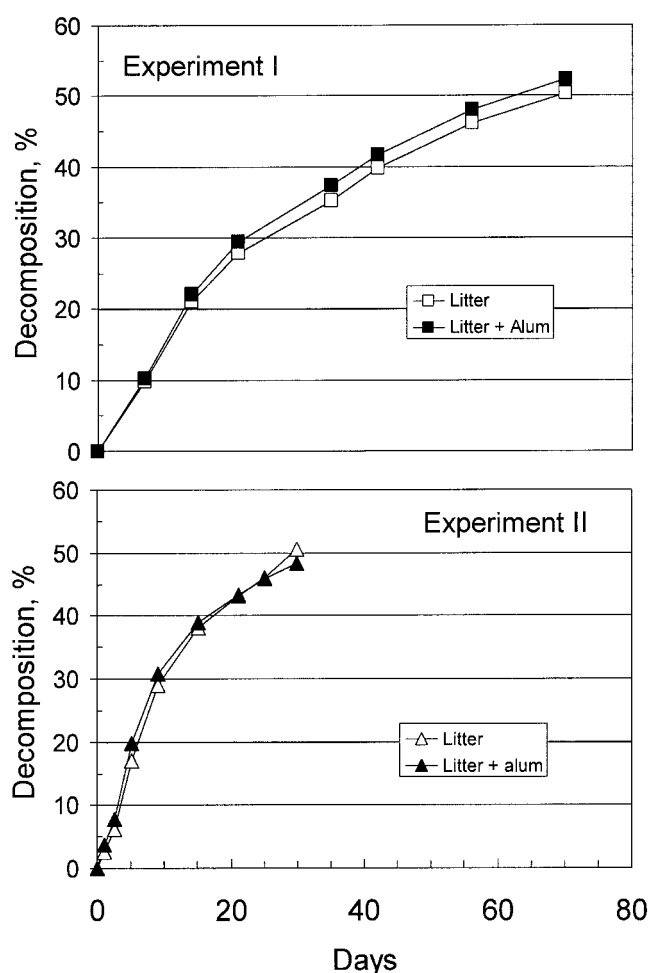
of 7.1 g kg⁻¹. This soil has a C to N ratio of about 10 (Gale and Gilmour, 1986). Initial ammonium and nitrate N concentrations were 9 and 4 mg kg⁻¹, respectively. The Cecil sandy loam total C and N contents were 5.2 and 0.38 g kg⁻¹, respectively, to give a C to N ratio of 13.7. Initial ammonium and nitrate concentrations were 1.1 and 1.6 mg kg⁻¹, respectively.

In Experiment I, litter plus alum contained significantly less total C and significantly more total N than unamended litter. The values for total C and total N were similar to those of Sims and Luka-McCafferty (2002) and Edwards and Daniel (1992). However, Sims and Luka-McCafferty (2002) reported little difference in total C or total N between litter from poultry houses treated with alum and those that had not been treated. The litter in Experiment II contained less total C and more total N and organic N than in Experiment I and those reported previously.

Decomposition

Percent decomposition versus time is shown in Fig. 1. Percent decomposition for litter amended with alum and unamended litter was not significantly different at any time for Experiment I. In Experiment II, small but statistically significant differences were noted early during the decomposition process (0–9.1 d). After that time, no significant differences in decomposition were found. At 30 d, 34% of the litter total C had been converted to CO₂-C in Experiment I, while 50% of the litter total C had been converted to CO₂-C in Experiment II. The two studies used different soil (Captina versus Cecil) and application method (surface versus incorporated) as well as litters from different flock cycles (five versus three), which had different C to N ratios. In addition, the number of alum applications varied. Any or all of these factors could have contributed to the differences in decomposition rate between the two studies.

Other studies have reported similar levels of decomposition for poultry wastes not amended with alum. Castellanos and Pratt (1981) found 45% decomposition in poultry manure after 28 d. They also showed that most of the CO₂-C evolution occurred in the first 14 d

**Fig. 1. Percent decomposition versus time.**

of incubation. After 30 d, Ajwa and Tabatabai (1994) found a mean value of 50% decomposition for poultry manure applied to three soils. Initial decomposition was very rapid, with more than 50% of the CO₂-C evolving in the first 5 d. Gale and Gilmour (1986) reported that 40% of a poultry litter had decomposed in 35 d. Gilmour et al. (1987) found that hen manure reached 64% decomposition over a 60-d period.

Net Nitrogen Mineralization, Soil Inorganic Nitrogen, and Ammonium Nitrogen

No effect of alum on net N mineralization in Experiment I was found (Table 2). At 42 d, the values ranged from 22 to 26%, while at 70 d the values ranged from 22 to 33%. Net N mineralization for Experiment II was from 15 to 17% at 17 d and from 12 to 15% at 30 d, again with no statistical differences due to alum addition. Thus, alum does not appear to affect net N mineralization of organic N in poultry litter in any consistent way.

Gale and Gilmour (1986) observed about 10% net N mineralization for poultry litter after 28 d of incubation. Other studies have shown larger amounts of N mineralization for studies using much longer incubation periods. Qafoku et al. (2001) reported a mean value of 51% net

Table 2. Soil net N mineralization, inorganic N, and $\text{NH}_4\text{-N}$ in litter amended soil.

Alum	Net N mineralization		Inorganic N [†]		$\text{NH}_4\text{-N}$	
	– % of organic N –		– mg N kg ⁻¹ –		– % of inorganic N –	
	Experiment I					
	42 d	70 d	42 d	70 d	42 d	70 d
–	26	22	284	273	92	61
+	22	33	341	411	89	81
LSD _{0.05}	NS	NS	NS	102	NS	NS
	Experiment II					
	17 d	30 d	17 d	30 d	17 d	30 d
–	15	15	56	56	12	6
+	17	12	52	59	6	7
LSD _{0.05}	NS	NS	NS	NS	NS	NS

[†] Control soil contained 39 (Run 1) to 44 (Run 2) and 49 (Run 1) to 51 (Run 2) mg inorganic N kg⁻¹ at 42 and 70 d, respectively, in Experiment I. Control soil contained 17 mg inorganic N kg⁻¹ at both times in Experiment II.

N mineralization (range 24–74%) for 60 poultry litters incubated for 112 d. Preusch et al. (2002) found that net N mineralization was from 42 to 64% of litter organic N for a 120-d study on four incorporated litters.

In Experiment I, at 42 d there were no consistent differences in soil inorganic N due to alum application, which contrasts with Moore et al. (1995), who reported that after 42 d, alum litter produced significantly higher levels of inorganic N compared with litter alone. At 70 d, there was a statistically significant increase in inorganic N due to alum treatment in agreement with the Moore et al. (1995) study. In Experiment II, alum did not lead to increases in soil inorganic N.

At 42 d, $\text{NH}_4\text{-N}$ was from 89 to 92% of the inorganic N ($\text{NH}_4\text{-N}$ plus $\text{NO}_3\text{-N}$) in Experiment I. At 70 d, the $\text{NH}_4\text{-N}$ ranged from 61 to 81% of the inorganic N. Alum did not significantly affect $\text{NH}_4\text{-N}$ percentage in Experiment I. In Experiment II, alum also did not significantly affect $\text{NH}_4\text{-N}$ percentage, although values were much lower than in Experiment I. These results suggest that other factors such as litter placement, litter type, litter treatment, or soil and not alum addition are important in nitrification of N mineralized from poultry litter during decomposition.

Conclusions

Decomposition and N dynamics for alum-amended litter differed little. Overall, results of many of the stud-

ies on litter not amended with alum should be applicable to alum litters.

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